TFAWS Active Thermal Paper Session

Thermal Design for Extra-terrestrial Regenerative Fuel Cell System

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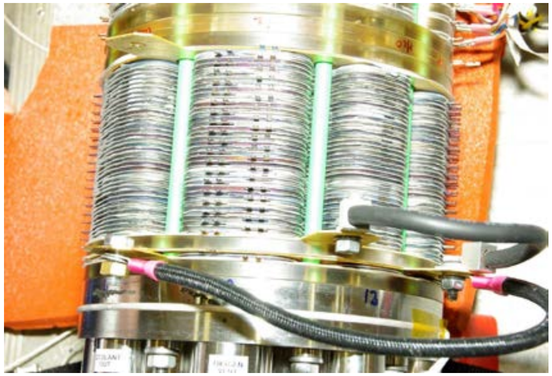
Regenerative Fuel Cell Systems

- Regenerative fuel cell (RFC)
  - Energy storage device
  - Utilizes a fuel cell to provide power and an electrolyzer to recharge
- Fuel cell
  - Electrochemical device that converts a fuel (hydrogen) and oxidizer (oxygen) into electricity and heat



- Electrolyzer
  - Electrochemical device that requires electricity to convert water to hydrogen and oxygen gas
- RFC surface power system concept
  - Use solar arrays during the day to provide customer power and recharge RFC
  - Use fuel cell stack to provide power during night time or eclipse

AMPS Fuel Cell Trade Study

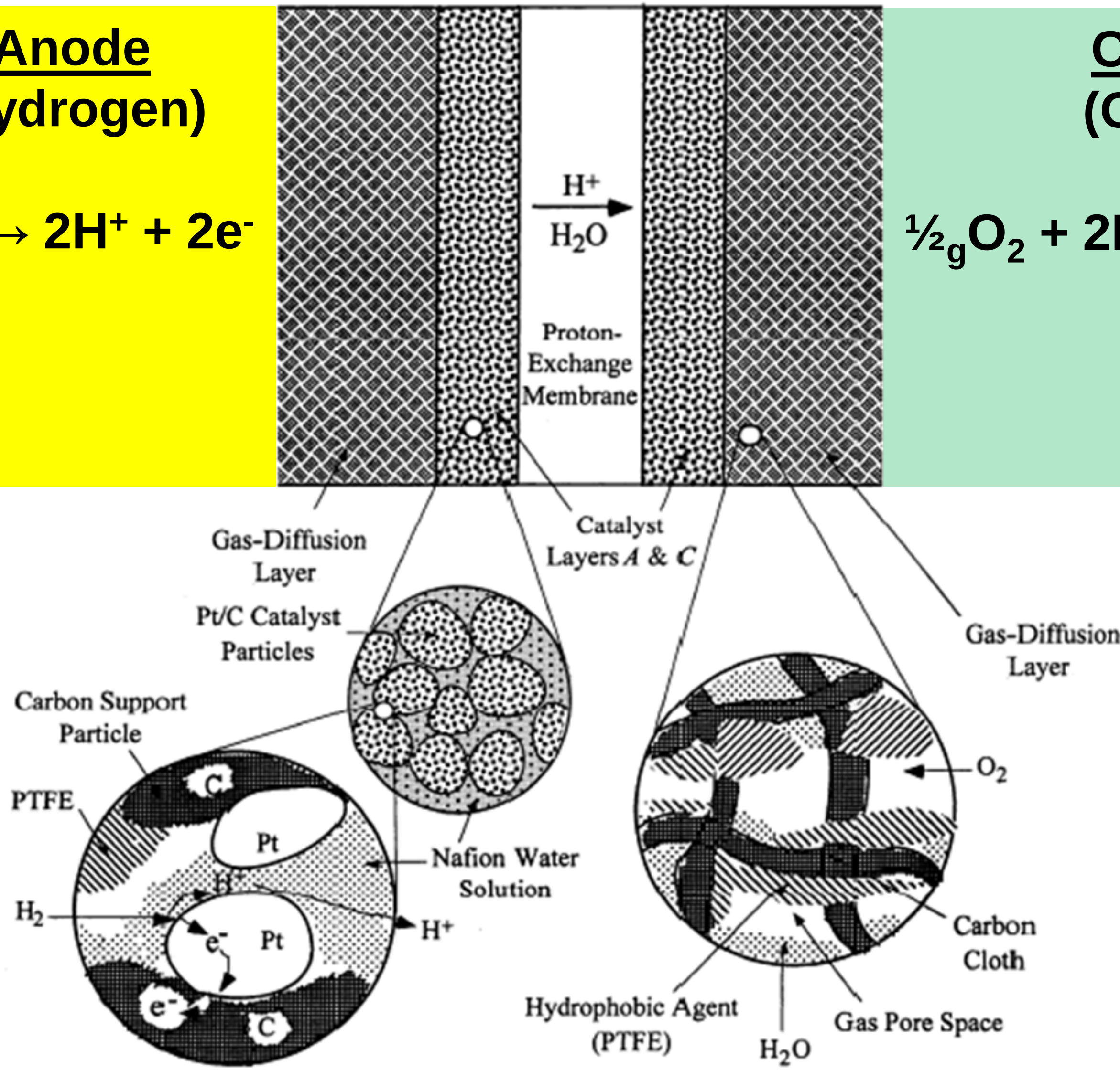
- The Advanced Exploration Systems- Advanced Modular Power Systems (AMPS) Fuel Cell Program performed a trade study between two fuel cell chemistries for a surface power system on either the Moon or Mars
- Fuel cell chemistries: proton exchange membrane fuel cell (PEMFC) and solid oxide fuel cell (SOFC)
- Four locations were considered: the Martian equator, the Jezero Crater on Mars (18 deg north latitude), the lunar equator, and the lunar south pole
- The goal of the trade study was to determine which FC chemistry is best suited for each application
  - Figures of merit: RFC mass, volume, round trip efficiency, and electric charge power required
  - Secondary goal is to identify technologies requiring further development

PEM Technology

Anode

(Hydrogen)

$_gH_2 \rightarrow 2H^+ + 2e^-$



Cathode

(Oxygen)

$\frac{1}{2}\,{}_gO_2 + 2H^+ + 2\,e^- \rightarrow H_2O$

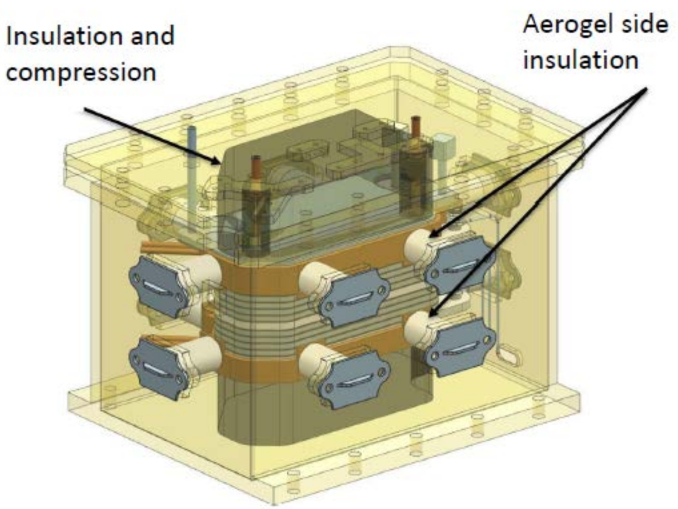
- **Operating temperature: 60 to 80 C**
- **Nominal operating pressure: 40 to 50 psia**

$$2\,{}_gH_2 + {}_gO_2 \rightarrow 2\,{}_lH_2O + 4e^- + Heat$$

Ref 1

SOFC Technology

- Ceramic electrolyte conducts oxygen anions across the cell
- Operates at high temperatures 600 C to 1000 C
- Operates at low pressures around 14.7 psia



Ref 3

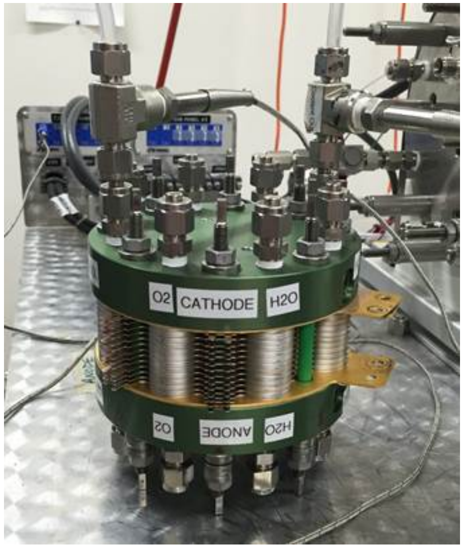
Ref 2

30-cell stack

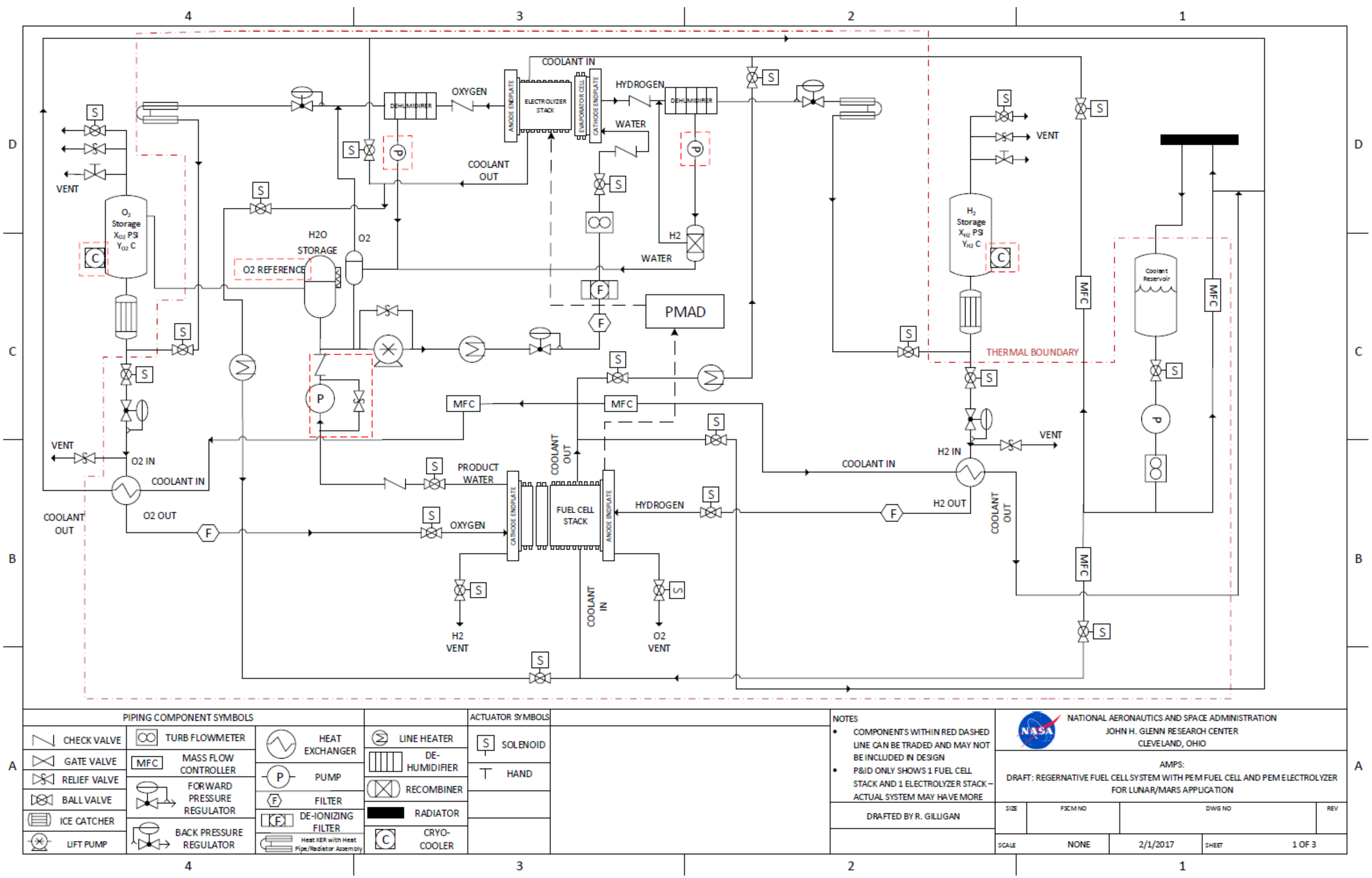
Ref 4

Thermal Requirements – PEM System

1. Reject waste heat produced by fuel cell and electrolyzer
   - FC considered produced 10 kW of electrical power and 7.6 kW of waste heat
   - Electrolysis is much more efficient and only produces around 1.5 kW of waste heat for 23 kW of input power
2. Minimize thermal cycling of fuel cell and electrolyzer
   - On/off cycles lead to degradation in fuel cell performance and reduce life of stack
   - Keep component in standby mode near its operational temperature
3. Avoid freezing of liquid water in system
   - PEM electrolyte (Nafion) is hydrated and is damaged from freezing
   - Liquid water coolant system used and must not freeze



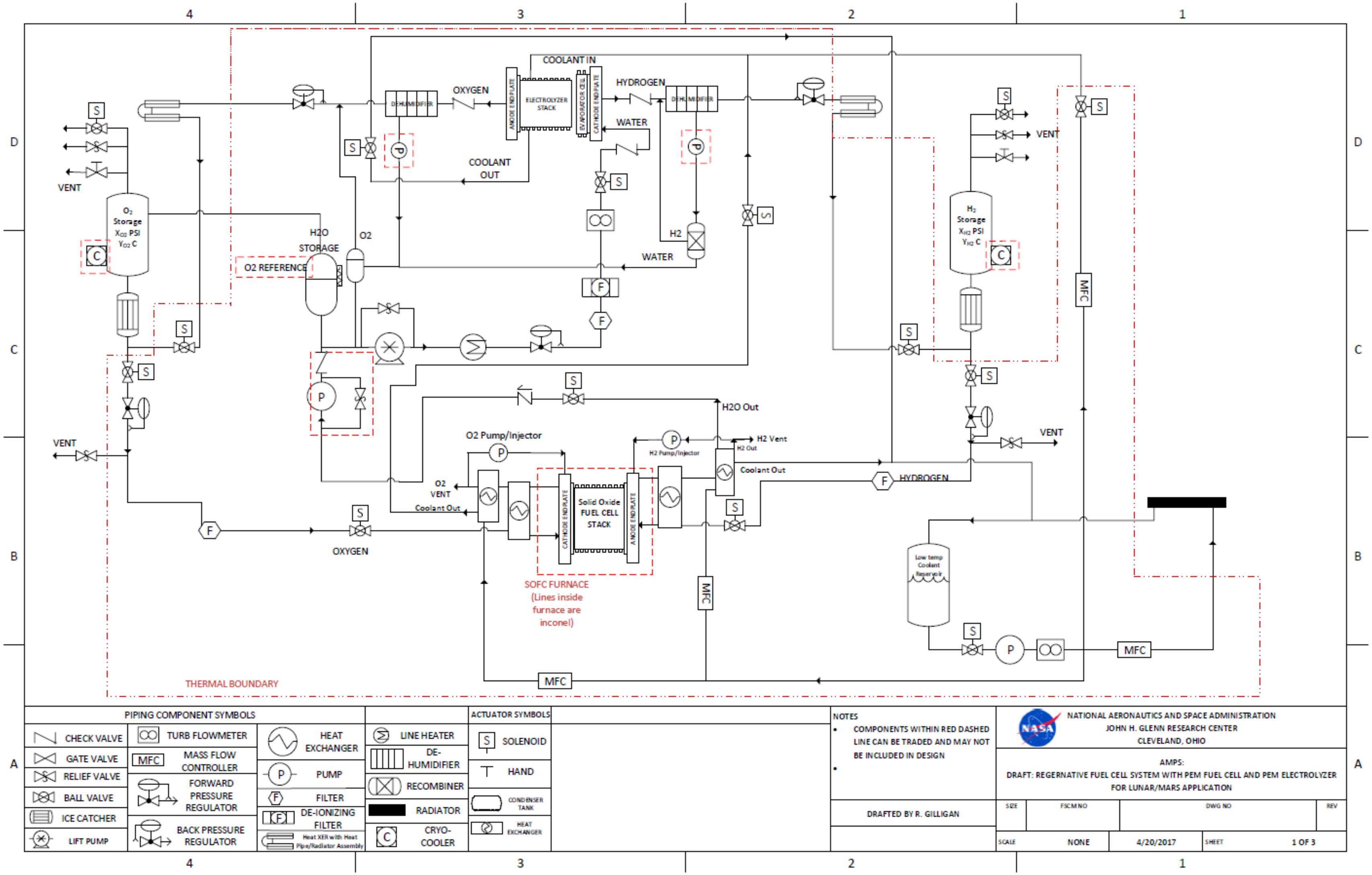
Notional P&ID of PEM FC RFC

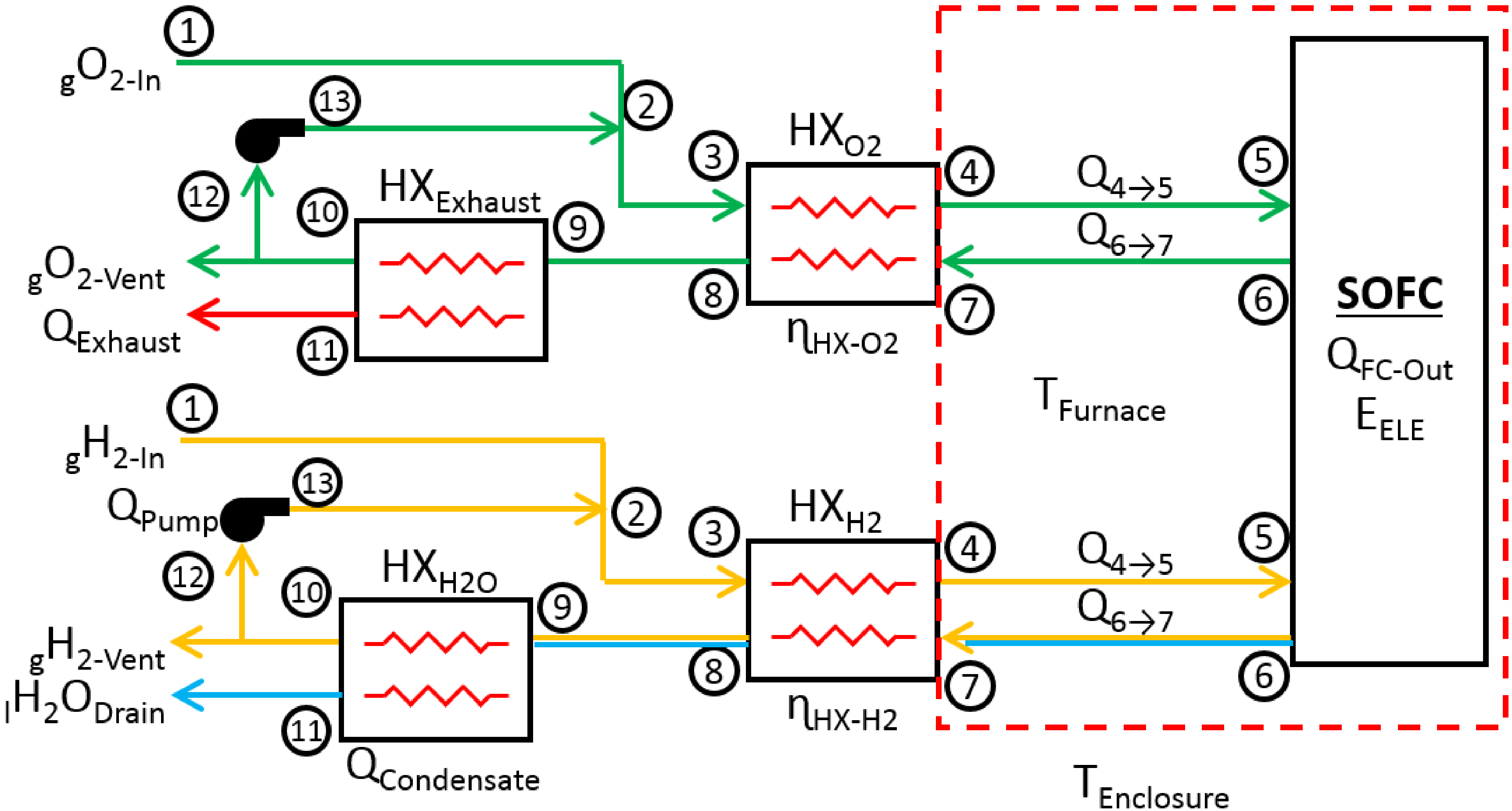


Thermal Requirements – SOFC System

1. Reject waste heat produce by fuel cell and electrolyzer
    1. Same as with PEM except SOFC are more efficient and produce less waste heat (3.4 kW); however must reject high quality heat
2. Minimize thermal cycling of fuel cell and electrolyzer
    1. On/off cycles are much more significant in SOFCs due to the large temperature difference between ambient and operating temperatures
3. Avoid freezing of liquid water in system
    1. Must feed either liquid or vapor water to PEM electrolyzer (EZ)
    2. Liquid water coolant system used and must not freeze

Notional P&ID of SOFC RFC



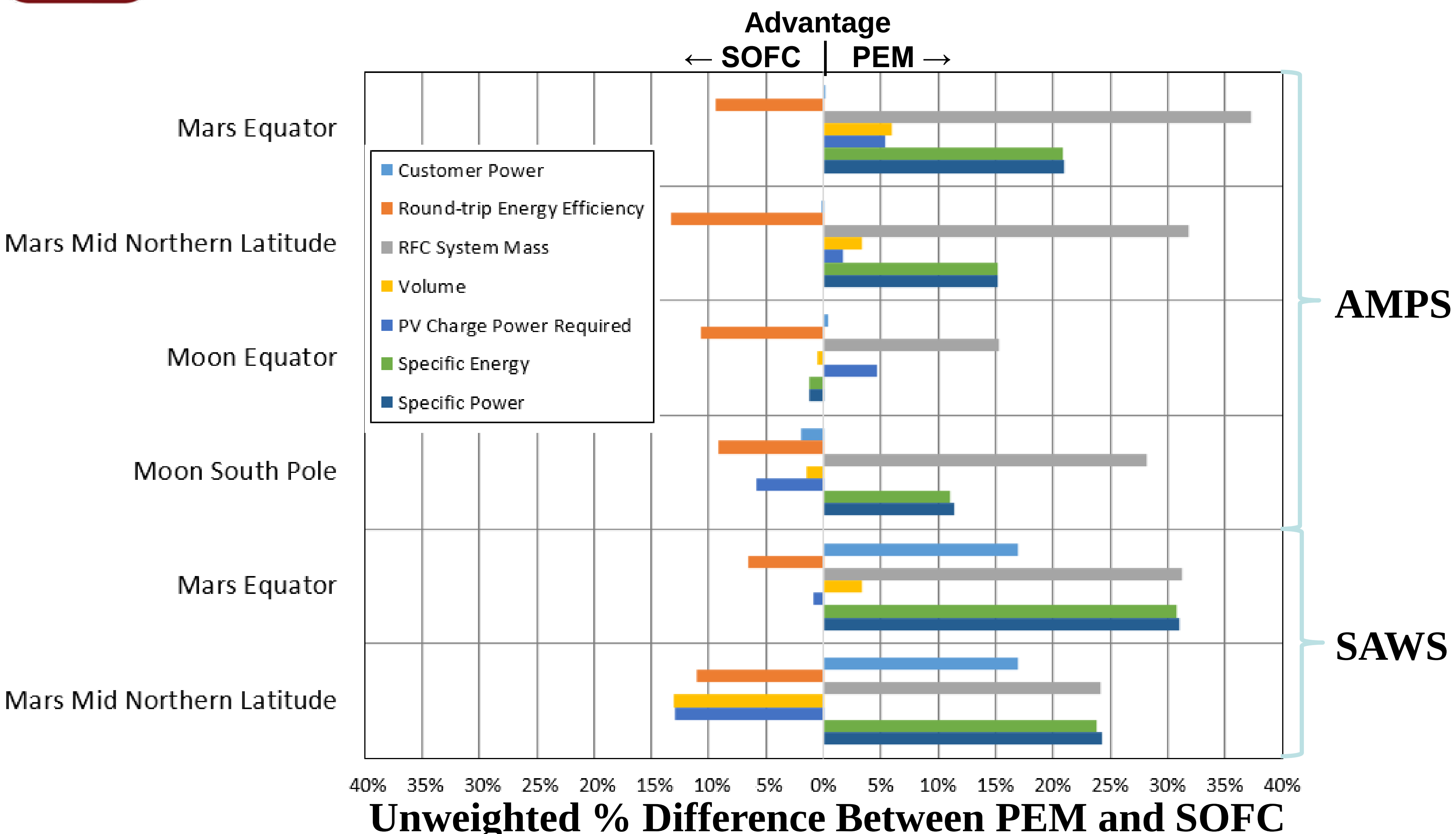


1
gO2-In
13
2
3
HXO2
4
Q4→5
5
12
10
HXExhaust
9
Q6→7
gO2-Vent
8
7
6
SOFC
QExhaust
11
ηHX-O2
QFC-Out
TFurnace
EELE
1
gH2-In
13
QPump
2
3
HXH2
4
Q4→5
5
12
10
HXH2O
9
Q6→7
gH2-Vent
lH2ODrain
8
7
6
11
ηHX-H2
QCondensate
TEnclosure

Summary

- Key hardware and concepts in PEM thermal system
  - Deionized water coolant loop
    - Coolant pump, coolant, coolant tank
    - Radiator (based on ISS DDCU design)
  - Use warm coolant to from operational component to maintain the temperature of the offline component
  - Thermal enclosure to insulate FC, EZ, coolant, and hardware
- Key hardware and concepts in SOFC thermal system
  - Thermodynamic analysis performed to determine temperatures/pressures at different locations
  - Heat exchangers sized using Q=UA*LMTD
  - Furnace used to maintain SOFC temperature
    - High temperature insulation and hermetic hot box to prevent external leakage
    - Electric heaters used to maintain SOFC temperature while in standby

Trade Study Results



$$\% \text{ Difference} = \frac{|PEM - SOFC|}{\left(\frac{PEM + SOFC}{2}\right)}$$

Technology Development Areas

- Water quality
  - Regenerative deionizing filter bed
- Material compatibility
  - Avoiding corrosion from deionized water
- Component Reliability
  - Martian mission duration considered was over 10 years with rare opportunities for performing maintenance
- Water vapor management in electrolyzer effluent
  - Regenerative dryer technology needed
- Fuel cell and electrolyzer stacks
  - Need for life testing data

QUESTIONS?

References

1. Baker, Ryan and Jiujun Zhang. “Proton Exchange Membrane (PEM) Fuel Cells”. Electrochemistry Encyclopedia. http://electrochem.cwru.edu/encycl/
2. “Mars Surface Systems Workshop – MOXIE Overview.” MIT and JPL.
3. Meyen, Forest. “Electrochemical Modeling, Characterization, Mars Oxygen In-Situ Resource Utilization Exp aenrdim Ceonnt t(rMolO oXf tIhEe).” FY17 Mars Surface Systems Workshop. Aug 1 2017.
4. Ryan, Abigail. “Steam Methane Reforming for Air-Independent Solid Oxide Fuel Cell Systems.” 2014 Fuel Cell Seminar.